Like mother (CERES), like daughter (Libera)

Libera Science Overview – Objectives, Methods and Applications

LASP

Jet Propulsion Laboratory
California Institute of Technology

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Jet Propulsion Laboratory, California Institute of Technology

2022 Earth Radiation Budget Workshop, Hamburg, Germany

Libera, NASA's first *Earth Venture* ***Continuity*** Mission

Overarching Science Goals

OG1: Provide seamless continuity of the Clouds and the Earth's Radiant Energy System (CERES) ERB Climate data record (CDR).

- Measurement of TOT, SW and LW with same characteristics as CERES to prevent gap in ERB Climate data record.

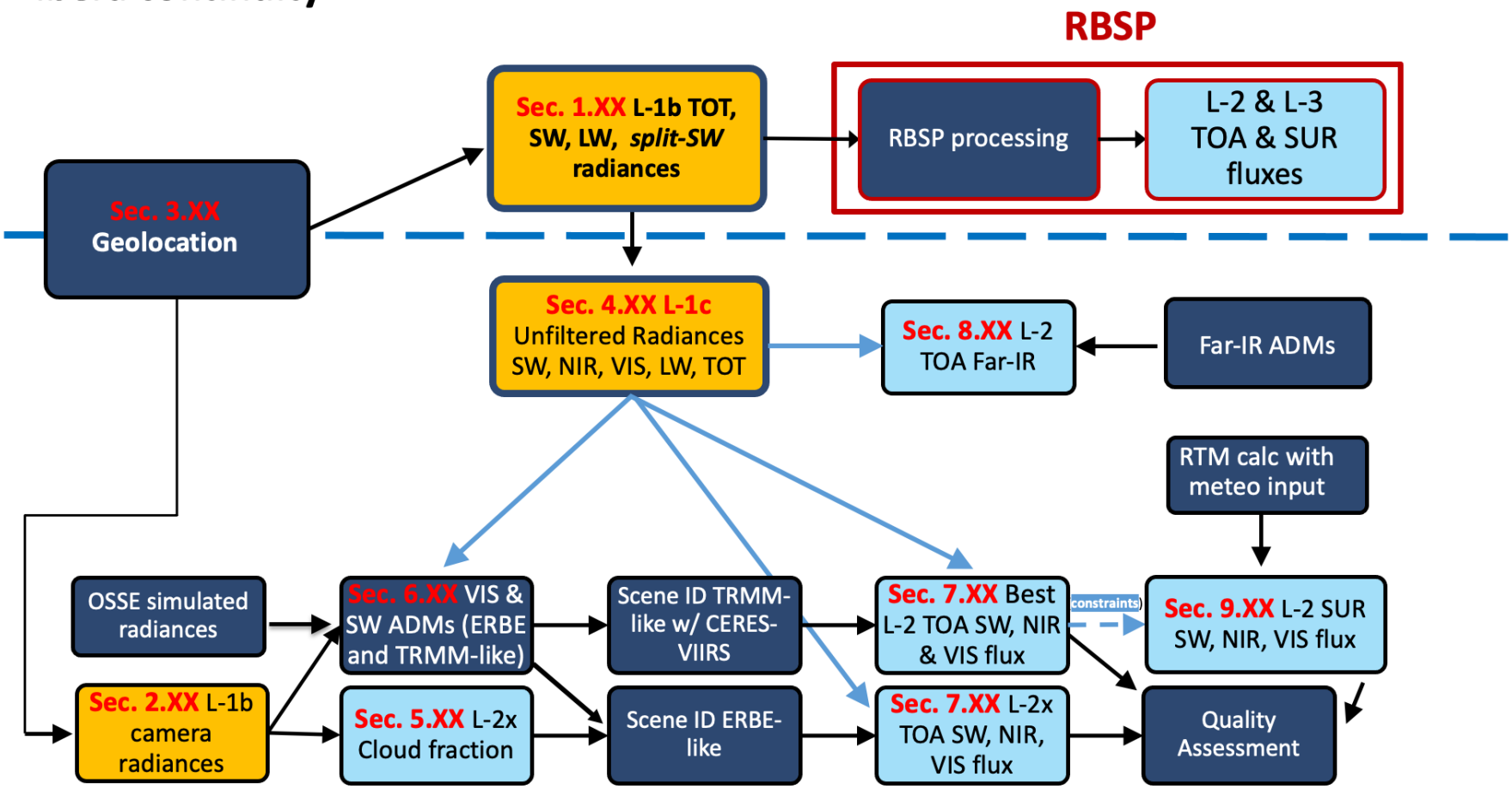
OG2: Advance the development of a self-contained, innovative & affordable observing system.

- Wide field-of-view camera for Scene ID and split-SW ADM development. **(next talk by Jake Gristey)**

OG3: Provide new and enhanced capabilities that support extending ERB science goals.

- **Additional split-SW channel to derive shortwave near-IR and visible irradiance.**

Libera continuity

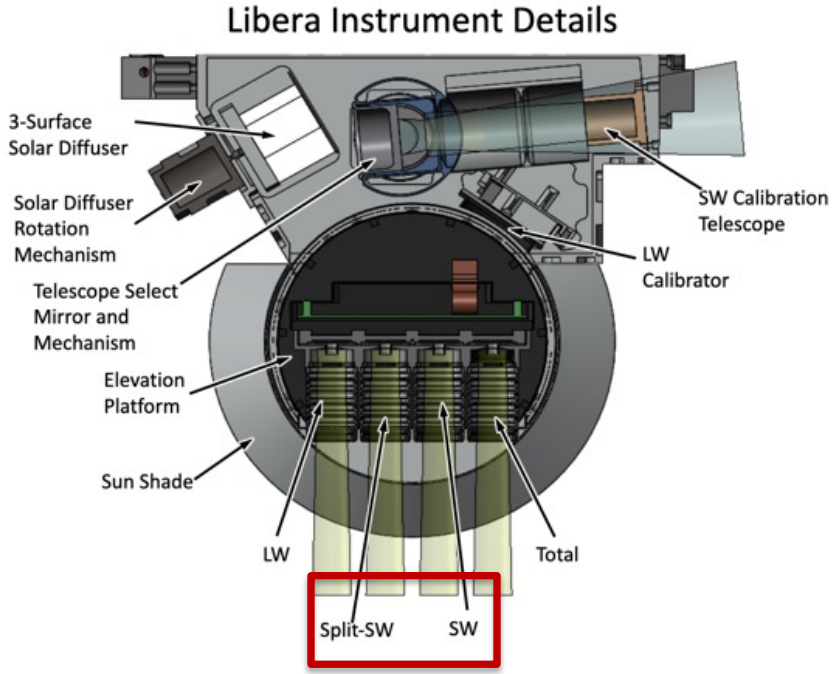


Libera beyond L-1b

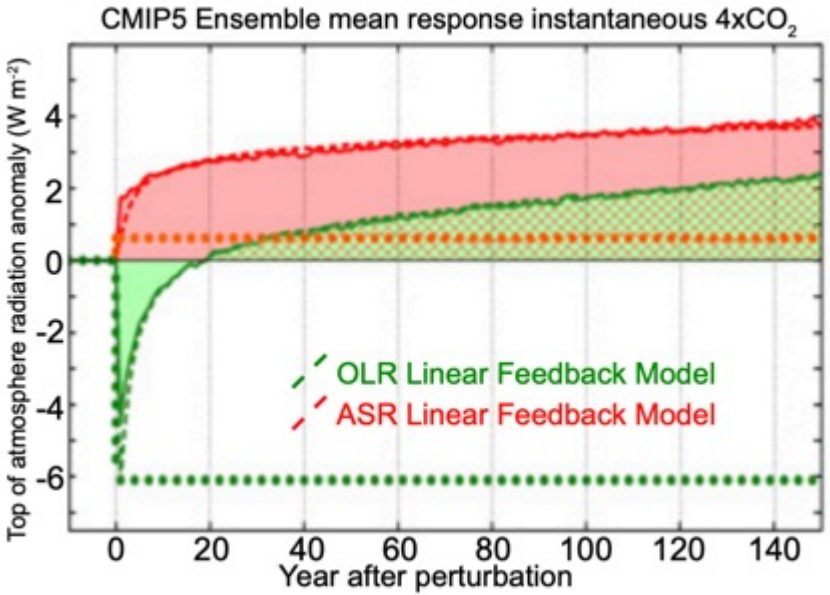
Libera's shortwave sub-band measurement

OG3: Provide new and enhanced capabilities that support extending ERB science goals

- Libera's fourth channel measures NIR at the same accuracy as the total SW radiance (0.2%)
- Retrieval of VIS, NIR, SW irradiance at TOA and surface:
  - NIR at 0.7-5 µm
  - SW at 0.3-5 µm
  - VIS radiance-to-irradiance **(J. Gristey, S. Schmidt)**
  - NIR = SW – VIS irradiance
- **Goals:**
  - **NIR & VIS signatures of processes that control the absorption of solar radiation & SW climate feedbacks.**
  - **Better understand the hemispheric symmetry of planetary albedo.**
  - Quasi-spectral model evaluation to reveal process-related biases



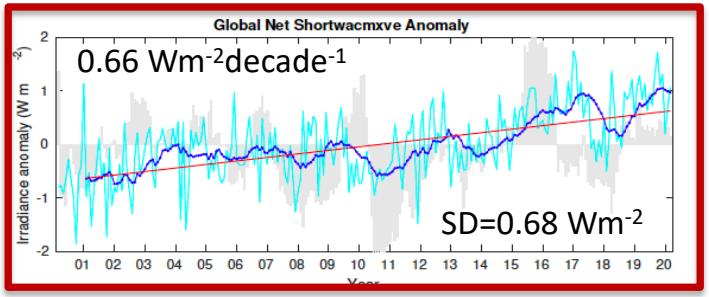
Motivation: Absorption of solar radiation warms our planet



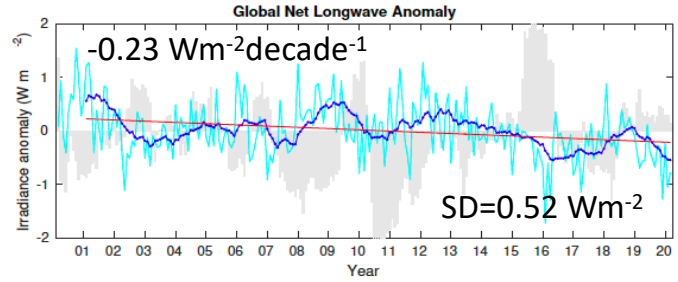
(Donohoe et al., 2014).

Climate model simulations suggest global warming is sustained by shortwave absorption (positive climate feedbacks). (Above is clear-sky only)

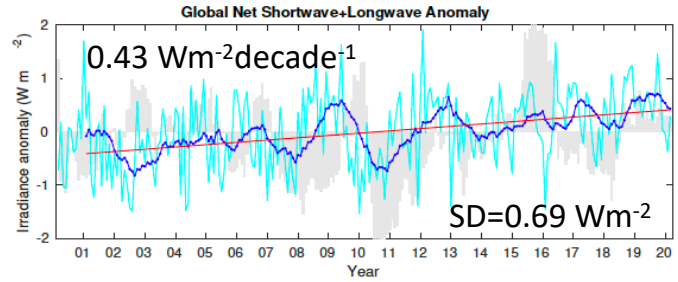
ASR



-OLR

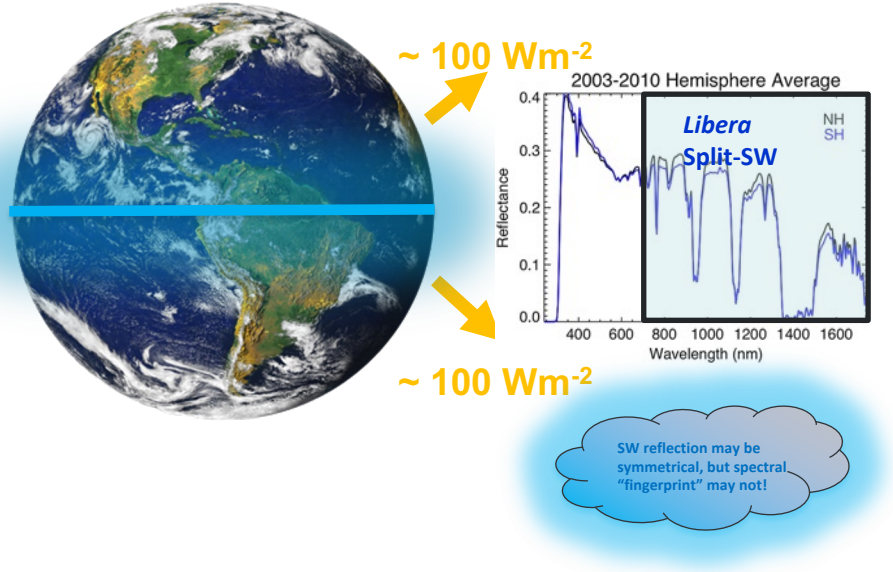


Net

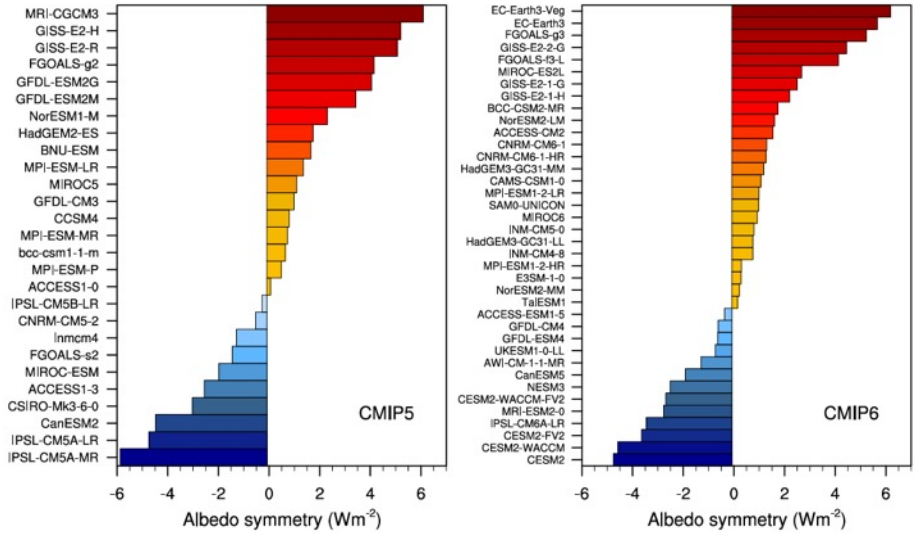


Stephens et al., 2022

Motivation: Hemispheric albedo symmetry



Rugenstein & Hakuba, subm.



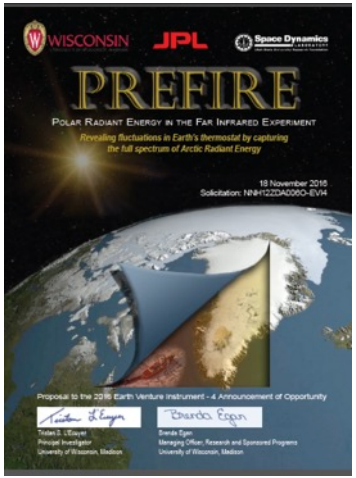
- Average and decreasing trends in albedo are symmetric across hemispheres
- Surface albedo asymmetry compensated by cloud asymmetry over extra-tropics, SH storm-tracks are 10% cloudier **(Datseris & Stevens; Jönsson & Bender)**

- 30% of models are symmetric within ± 1 Wm^{-2}
- 70 (80)% of models are symmetric within ± 4 Wm^{-2}. (~3 times more heat transport across equator!)
- **Very strong evidence that forcing yields NH to darken faster than SH – the future may be asymmetric**

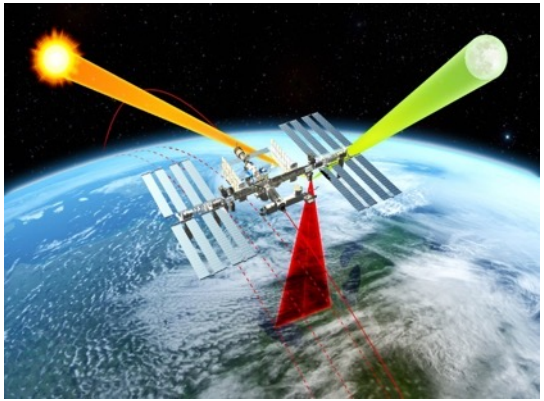
Motivation: The future is spectral

- Spectral signatures of the TOA fluxes reveal insights into processes that shape the ERB and changes to it
- Measurements are on the way:

Spectral OLR – 2022 (L'Ecuyer)



CLARREO-PF - 2022 spectral SW (Shea)

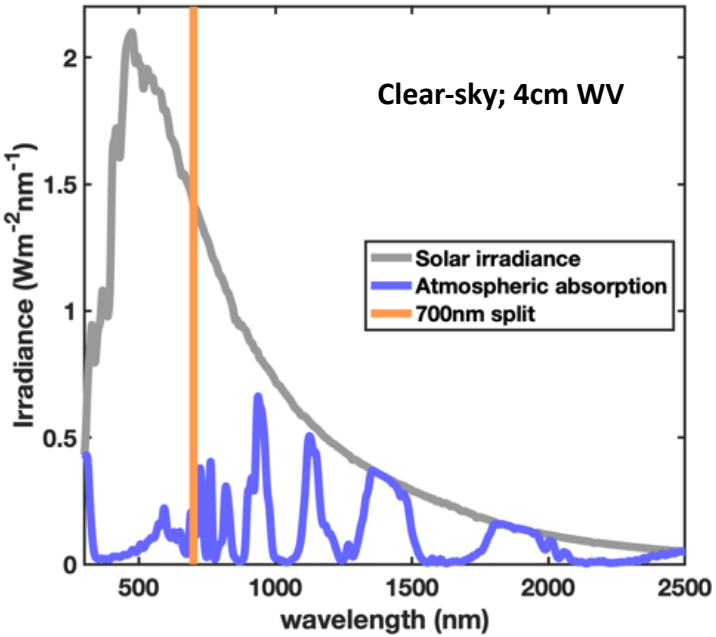


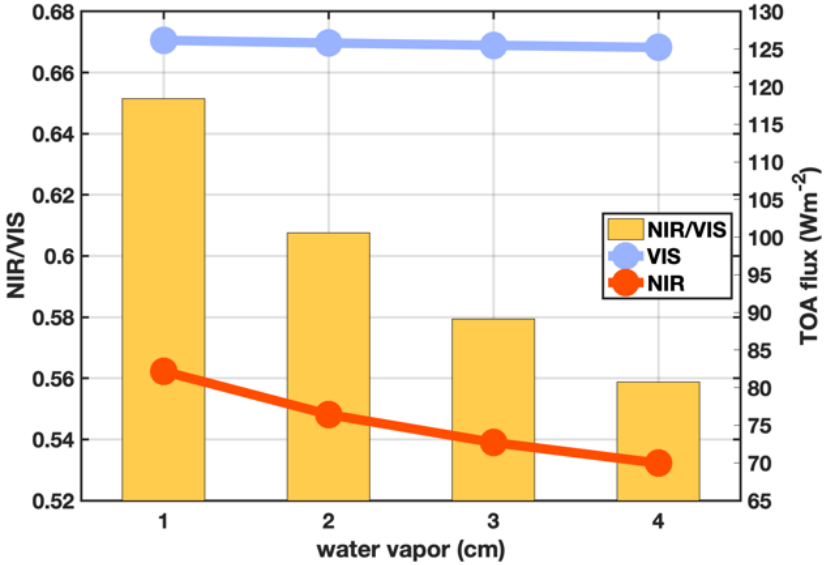
X-element linear array of absolute radiometers to enhance spatial & spectral resolution (Coddington)

Libera-FO?

Spectral nature of shortwave radiation according to MODTRAN

Water vapor absorption (MODTRAN calc. by Bruce Kindel, LASP)





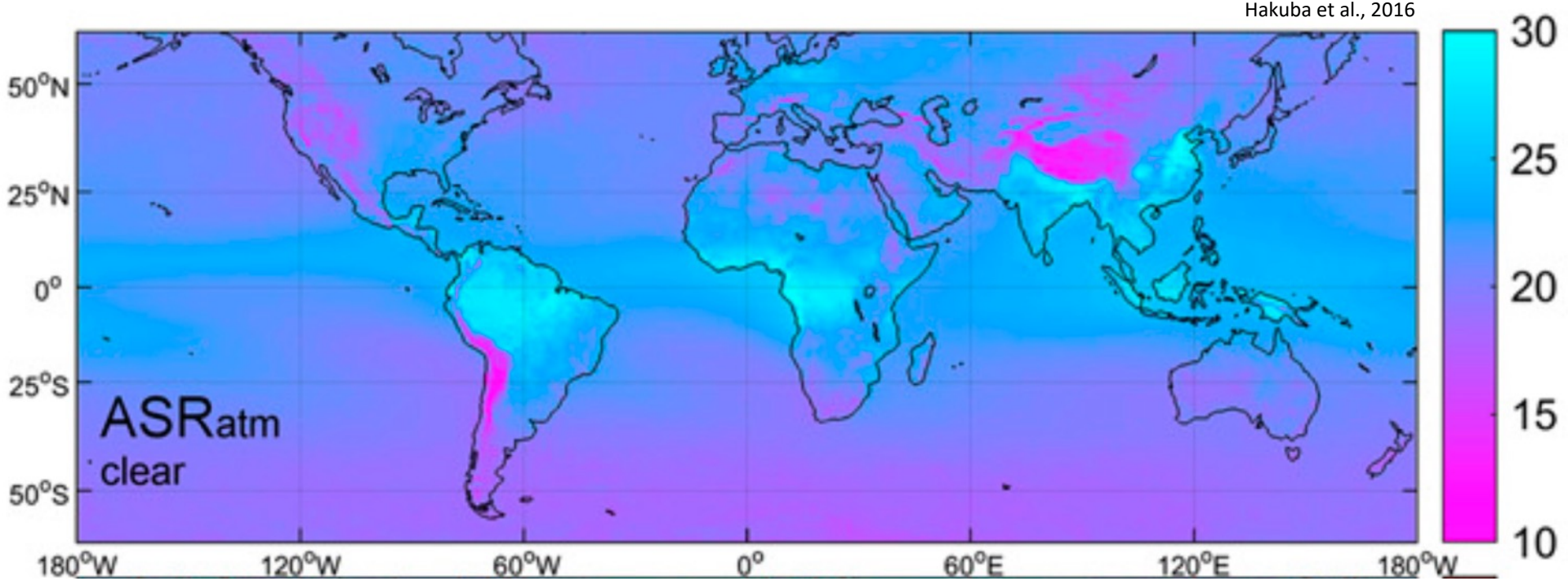
Water vapor absorption dominates in the NIR; ~6 Wm^{-2}/cm NIR absorption

C-C 7%/K ~ 0.2cm/K ⟶ ~ 1 Wm^{-2} NIR absorption

Clear-sky atmospheric shortwave absorption

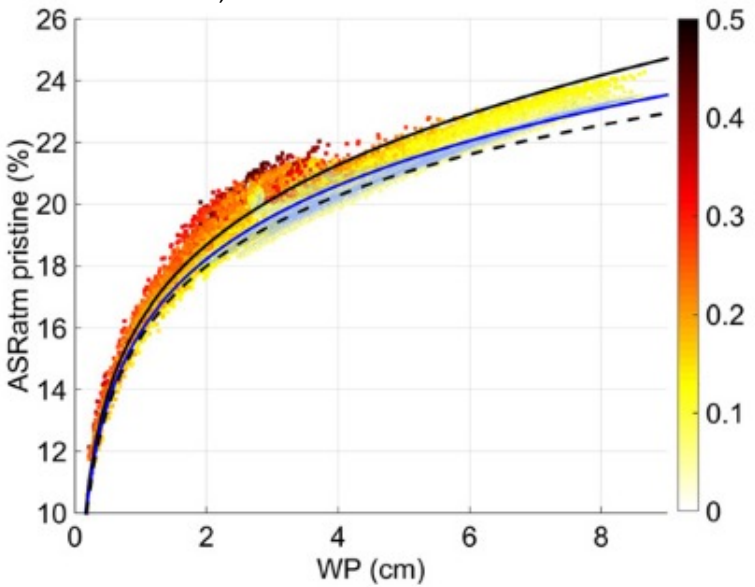
% of Solar incoming

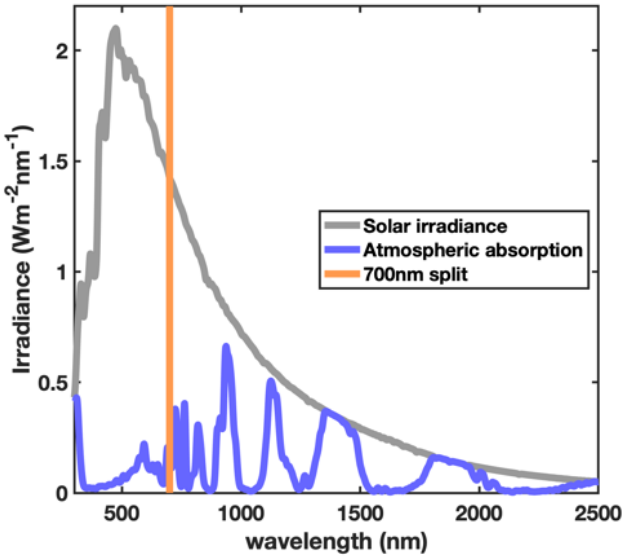
Hakuba et al., 2016



Surface albedo impacts water vapor absorption

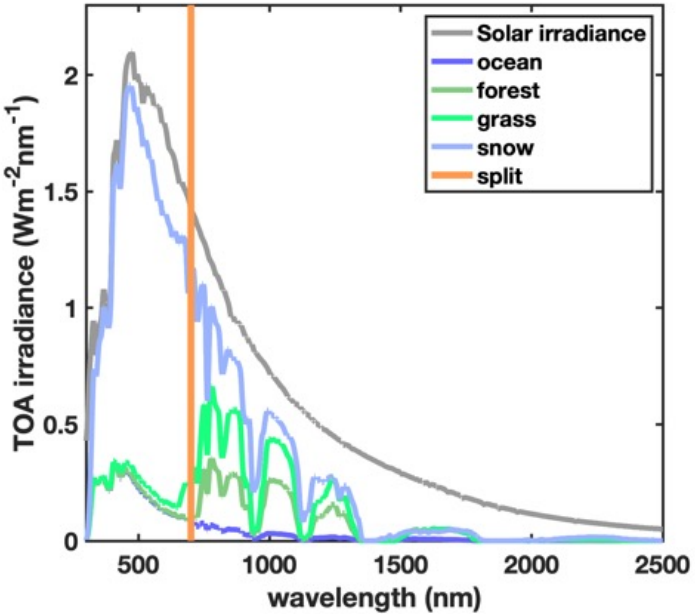
Hakuba et al., 2016

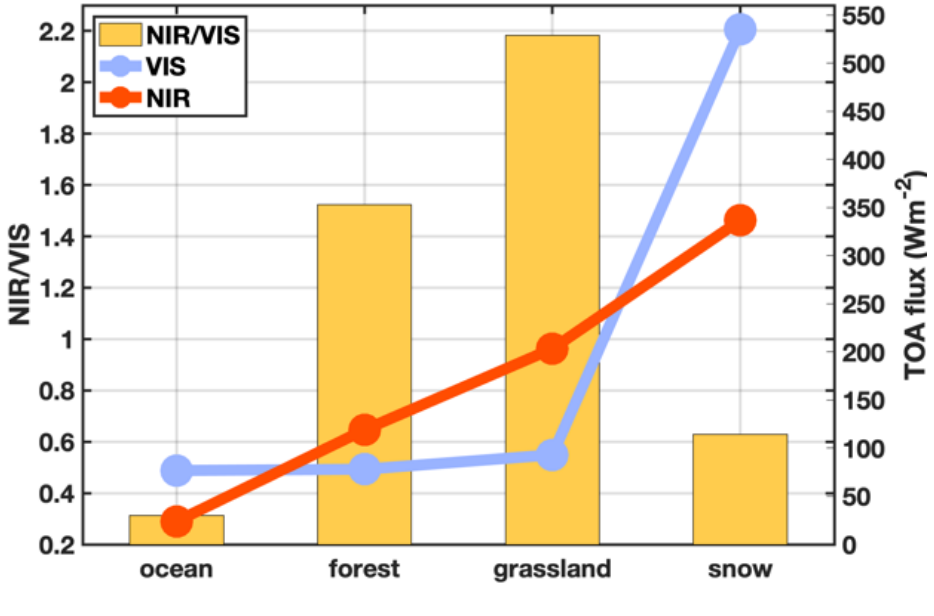




- **Water vapor saturation yields non-linear increase**
- **Underlying surface albedo impacts relationship by several Wm^{-2}**
- **WV over 'brighter' surfaces yields large clear-sky atmospheric absorption – in particular over vegetated land?**

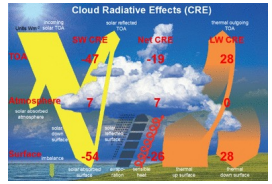
Spectral nature of surfaces

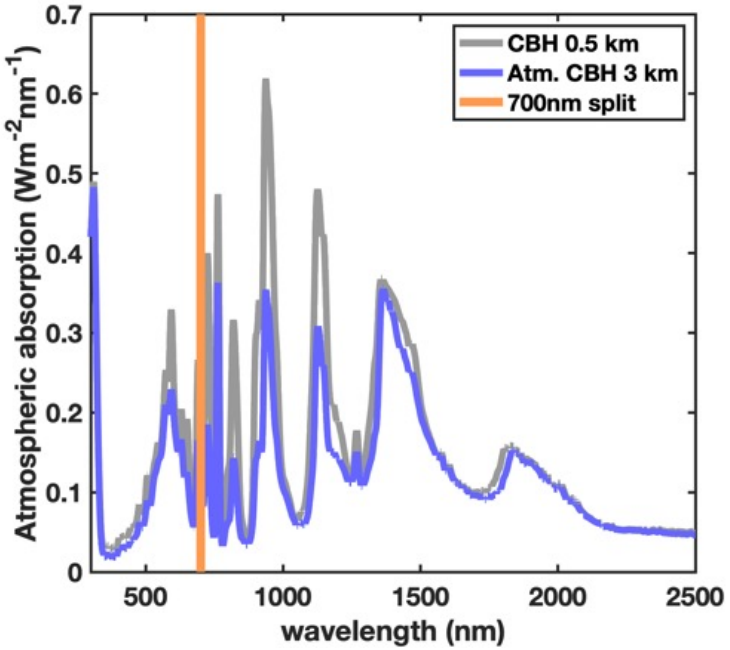


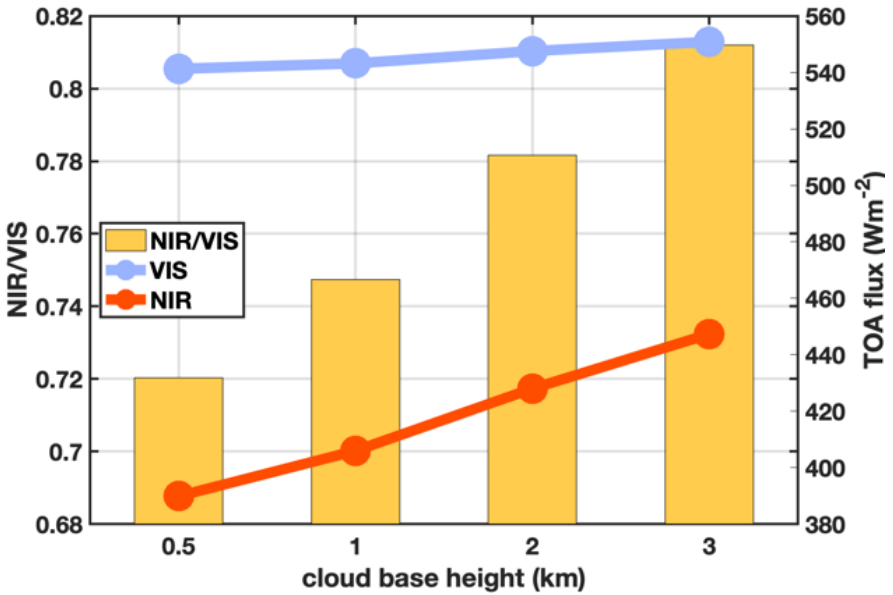


Different surface types associated with very different NIR/VIS ratios (~NDVI); Libera's NIR/VIS may help track land cover change and impact on ERB

Good old cloud absorption





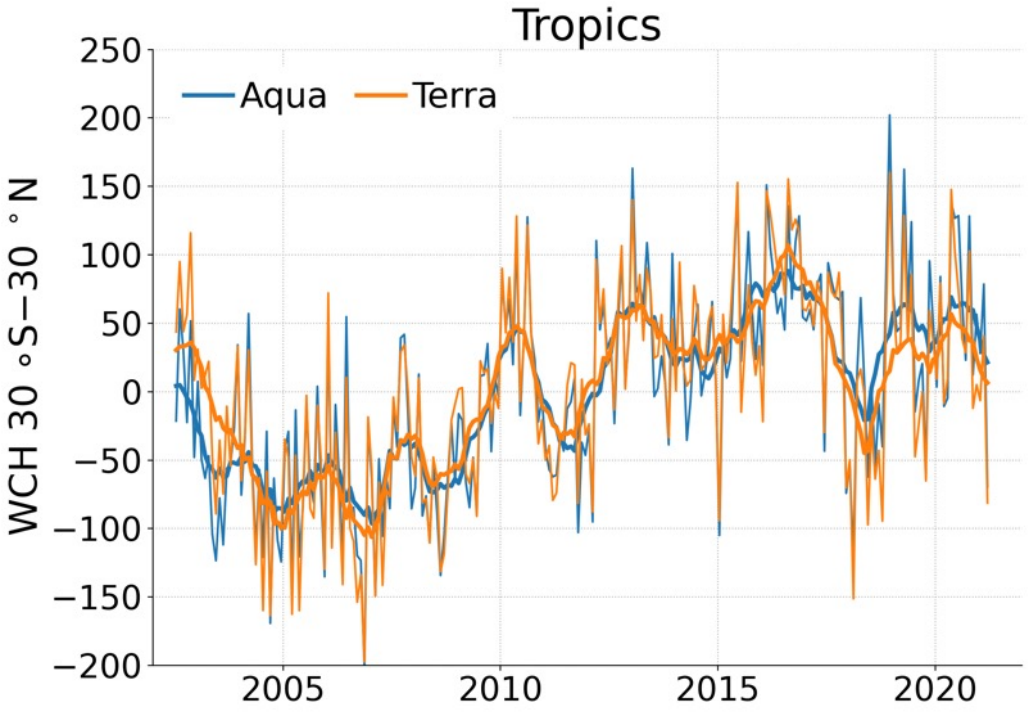


Cloud SW absorption is ~15 % of SW CRE (~47 Wm^{-2}) and subject to change; example shows impact of cloud base height, shifting the ratio in favor of NIR_{TOA} (2.5 Wm^{-2}/100m

Change in cloud height alone does impact albedo!?

Tropical clouds are getting higher

Richardson et al., 2022



Cloud height trend sensitivity: 330±60 m K^{-1}

"Wild" estimate based on idealized MODTRAN analysis: ~8 Wm^{-2} / 330m NIR_{TOA} reflection.

NIR and VIS absorption and albedo in an Earth system model.

UKESM1 SW, NIR, and VIS fluxes

- UK Earth system modeling project
- Successor to HadGEM2-ES
- “The complexity of coupling between the ocean, land, and atmosphere physical climate and biogeochemical cycles in UKESM1 is unprecedented for an Earth system model.” (Sellar et al., 2019)
- Limits of spectral intervals (wavelengths in m.)

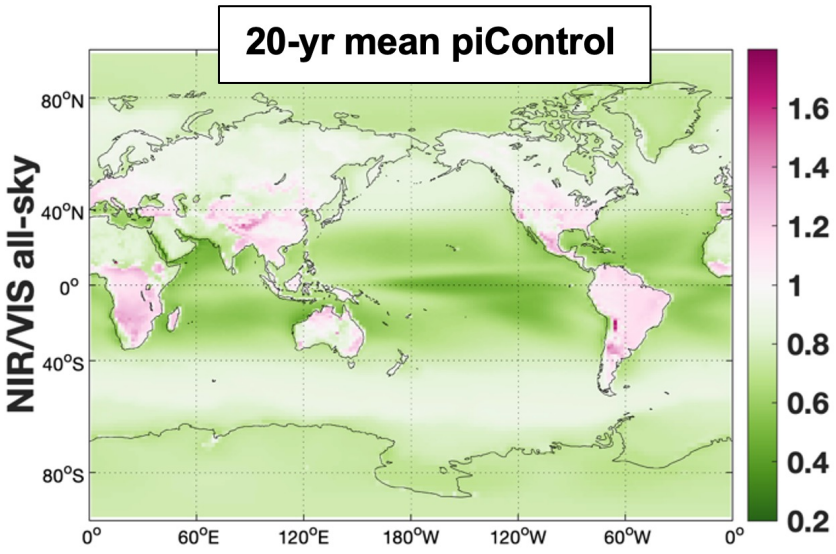
Band	Lower limit	Upper limit
1	2.000000000E-07	3.200000000E-07
2	3.200000000E-07	5.050000000E-07
3	5.050000000E-07	6.900000000E-07
4	6.900000000E-07	1.190000000E-06
5	1.190000000E-06	2.380000000E-06
6	2.380000000E-06	1.000000000E-05

- Integrate bands 2-3 for visible, and bands 4-5 for near-IR

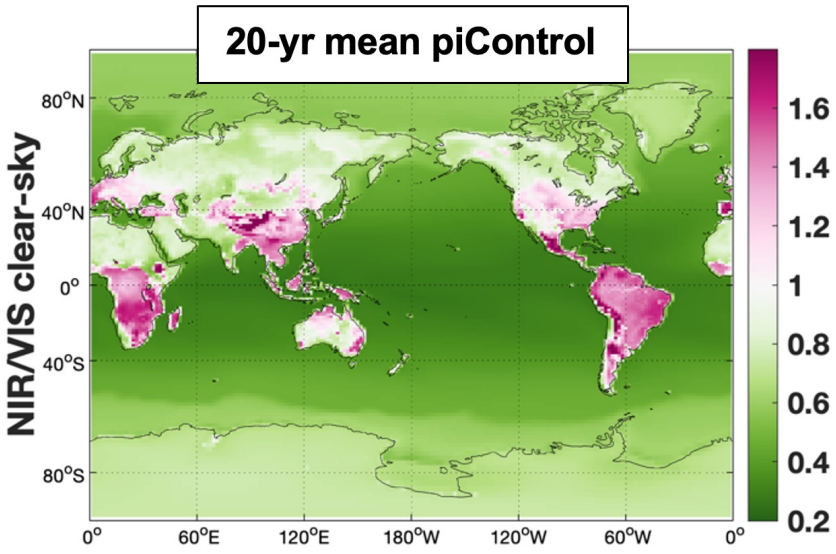
Model simulation:
Alejandro Bodas-Salcedo

NIR/VIS in UKESM1 – preindustrial conditions

NIR/VIS	0.79



NIR/VIS	0.59

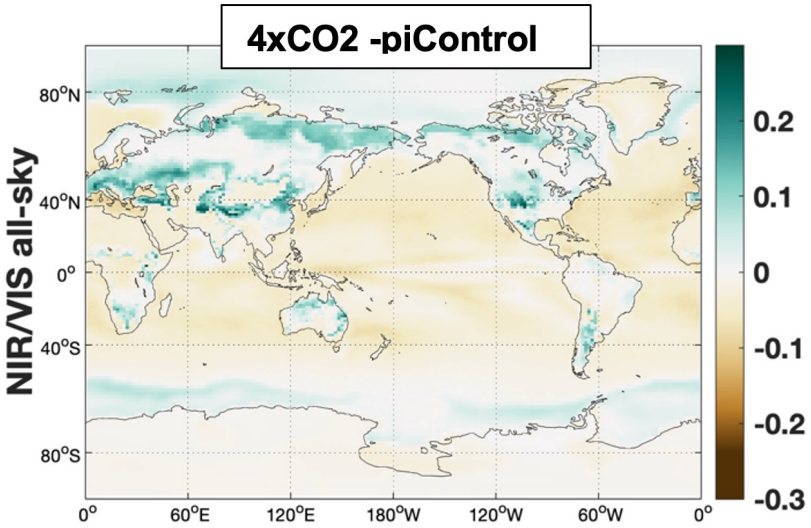


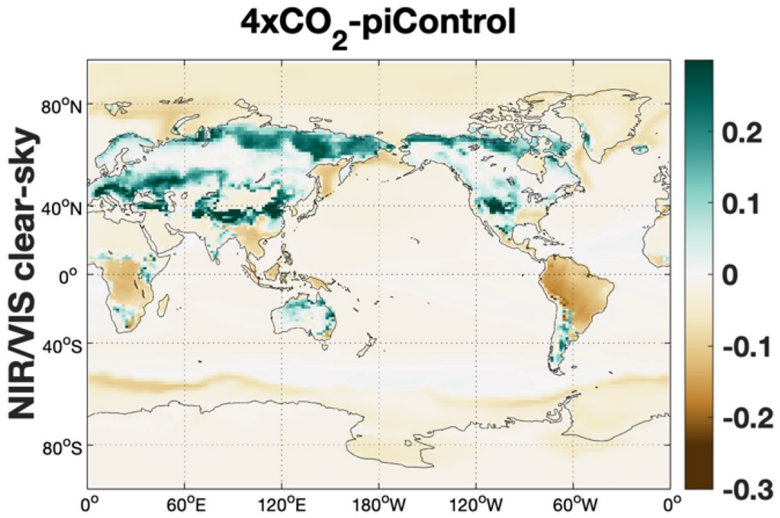
NIR/VIS in UKESM1 – 4xCO_2 - preindustrial conditions

The greening and browning of the future

NIR/VIS	0.77

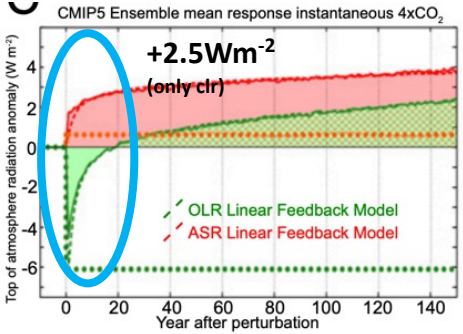
NIR/VIS	0.57

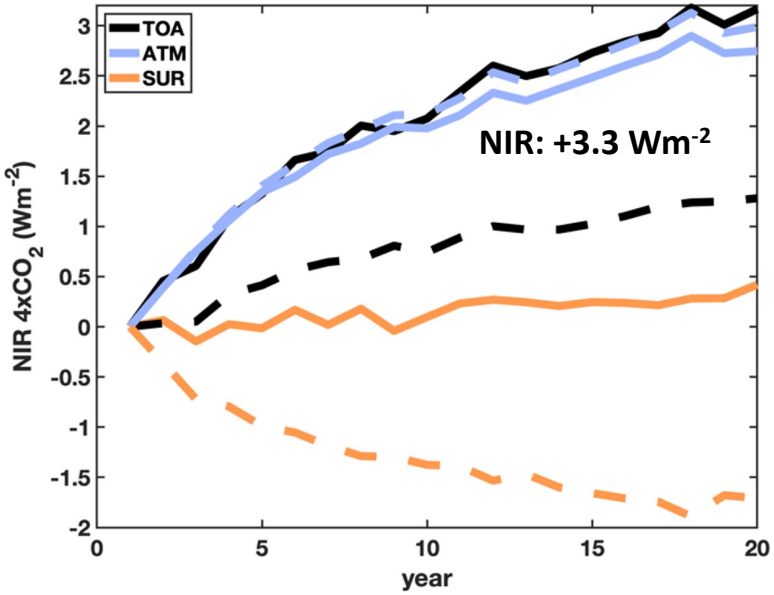


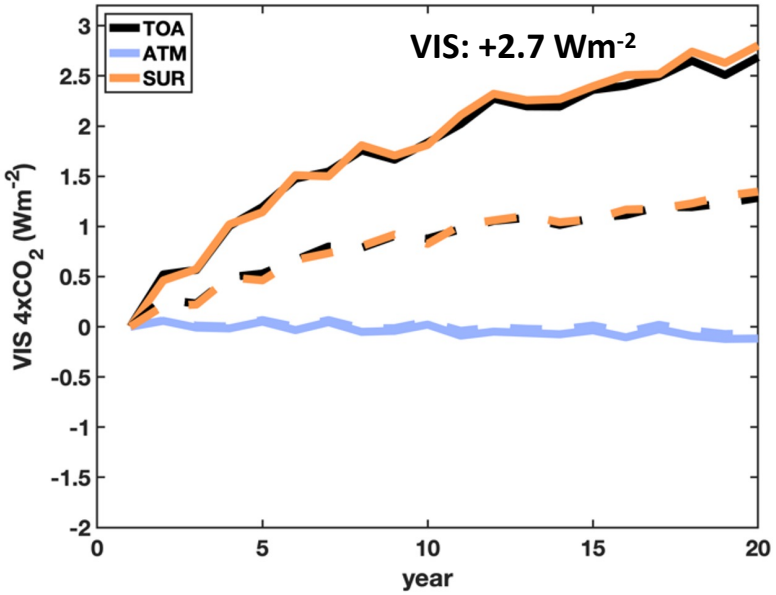


Long-term SW absorption change in UKESM1

- Clear-sky absorption: ~ 2.5Wm^{-2} (in line with Donohoe et la., 2014)
- All-sky: ~ 6Wm^{-2}
- SUR/ATM ~ 50% 2.5Wm^{-2}

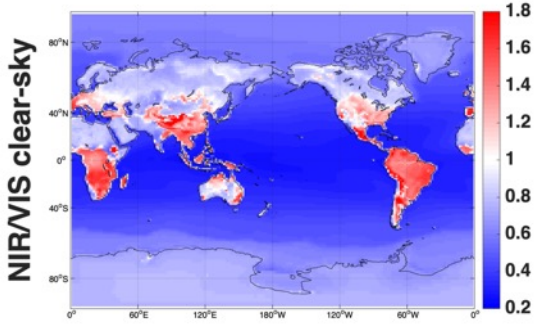


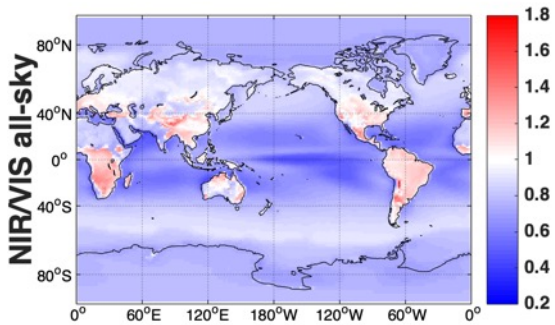


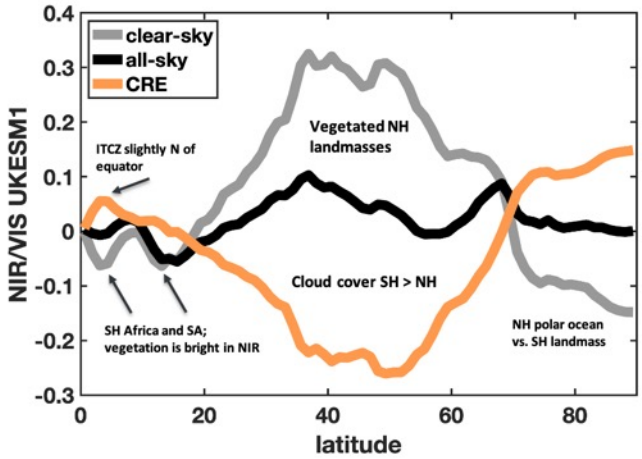


UKESM1 is symmetric in albedo and NIR/VIS (20y pi control)

All-sky	Glo	NH	SH
TOT SW	99.3	**99.1**	**99.6**
NIR	44.0	44.2	43.7
VIS	55.0	55.8	55.4
NIR/VIS	0.79	**0.80**	**0.78**
Clear-sky	**Glo**	**NH**	**SH**
TOT SW	54.4	57.4	51.4
NIR	20.2	22.3	18.2
VIS	34.2	35.1	33.2
NIR/VIS	0.59	**0.63**	**0.55**







- Clear-sky hemispheric “land-sea contrast”, NIR/VIS high over land
- CRE increase NIR/VIS especially over SH ocean
- CRE diffuse spatial gradients in NIR/VIS
- **Clouds not only balance mean albedo and trend across hemispheres but also NIR/VIS ratio!!**

Outlook: Libera SW sub-band measurement

- Three idealized process examples indicate NIR is particularly sensitive to changes in climate relevant processes
- Set expectations for NIR/VIS of different processes and scene types
  - NIR & VIS calculations over CERES period; spectral OSSE; spectral GCM output
  - Define metrics & processes of interest
- Improved knowledge of SW absorption processes and change therein can help understand bigger picture mysteries… or unveil **more mystery**…

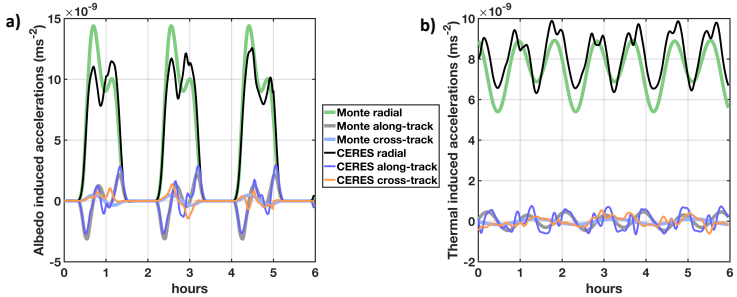
  Although NIR/VIS driving processes are completely different, UKESM1 suggests:
  - NIR/VIS is balanced across hemispheres
  - NIR and VIS change in concert under forcing - Past NIR/VIS = future NIR/VIS

Challenges - the future of ERB

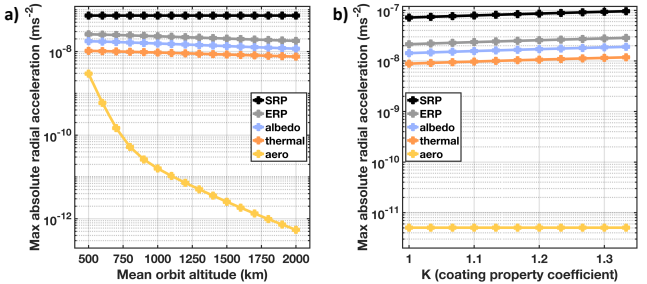
- **Threat of continuity-gap is real – both before and after Libera**
- **Future looks like “many smaller platforms” (constellations/formations)**
  - **the future is here for precipitation (TROPICS, INCUS)**
- **Spectral info content – more use cases and tools to evaluate climate models**
- **Earth energy imbalance companion missions that target direct EEI measurement**

  Simulation environment for “Space Balls” – accelerometric EEI approach via radiation pressure **(Hakuba et al., 2019, 2022)**

Ingesting CERES irradiances for use in mission design software



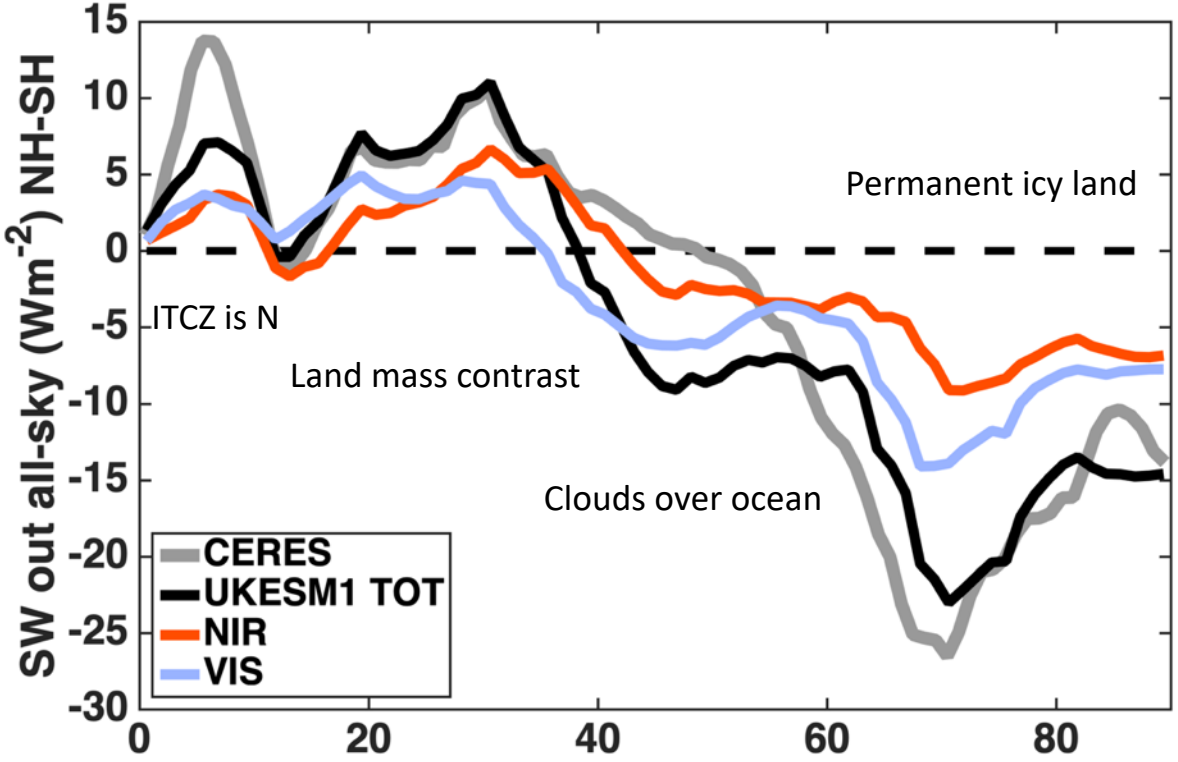
Sensitivities are studied to inform on confounding forces and design



Thank you for your attention

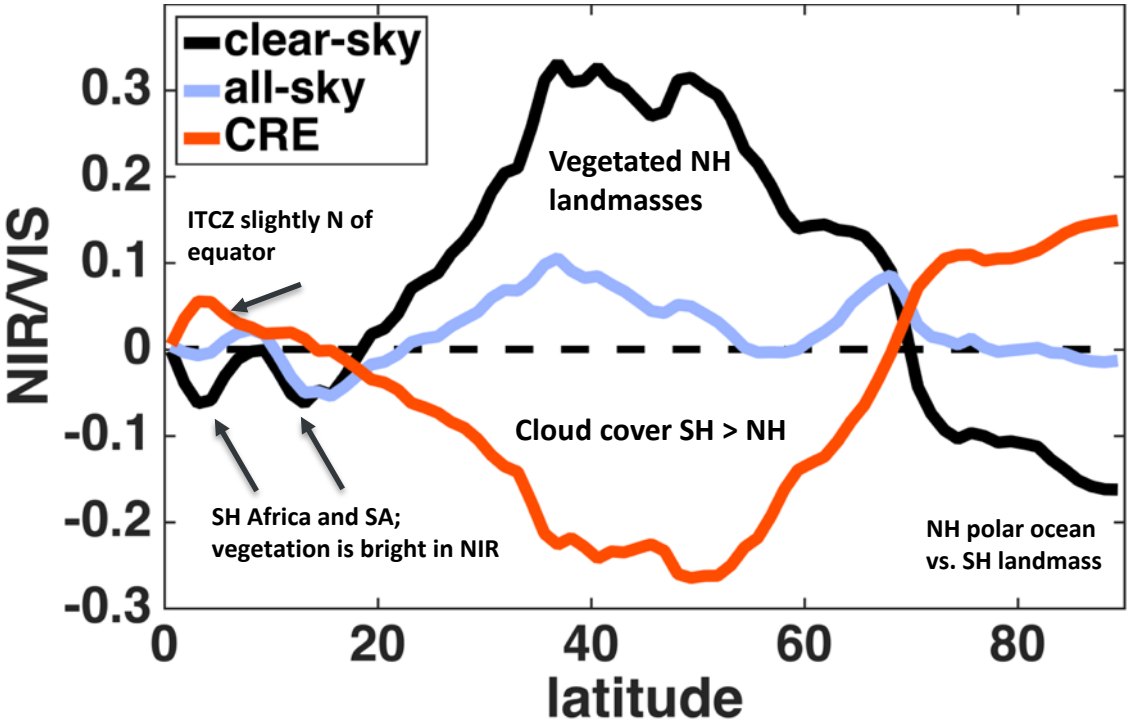
Back-up

NH-SH differences per latitude

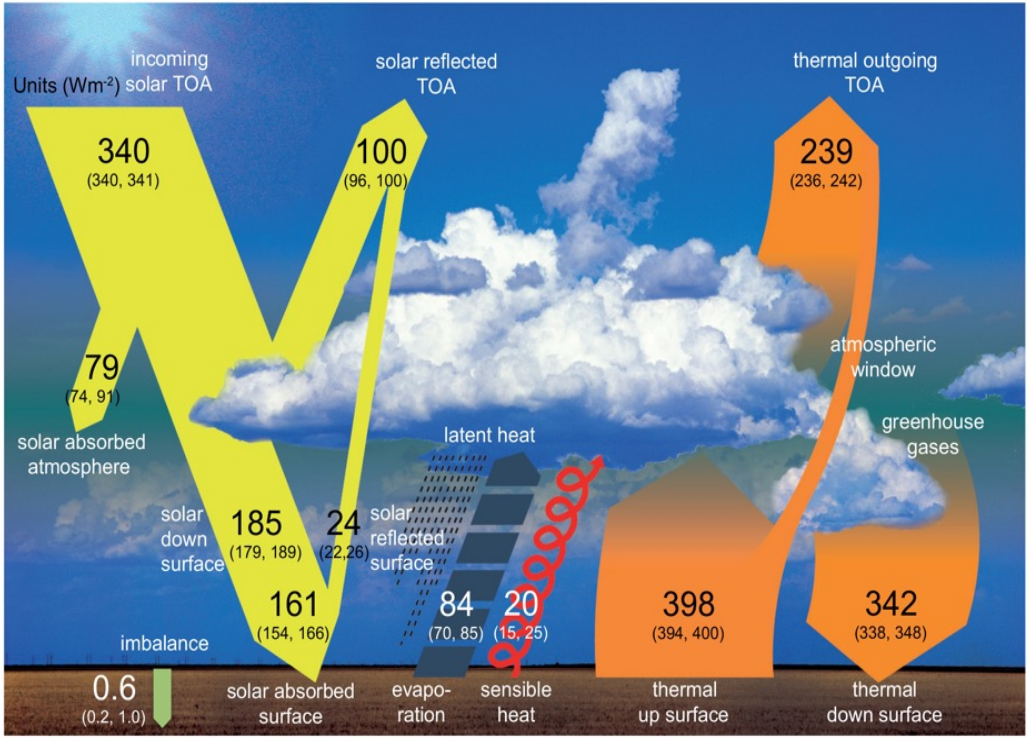


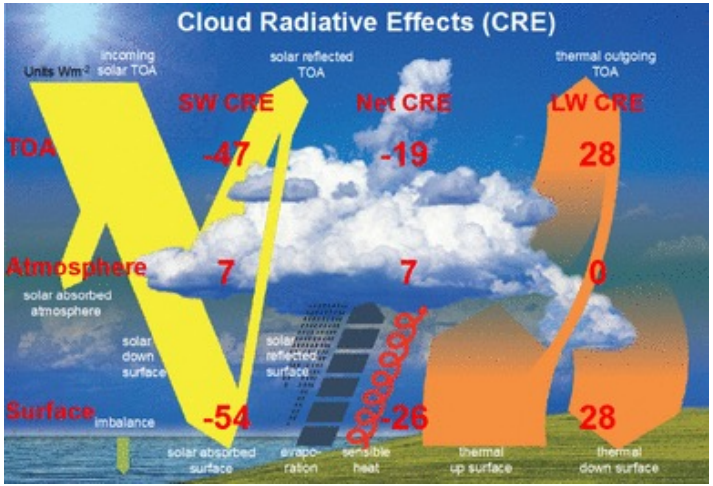
- NH is mostly brighter over 0-40 degree, but darker poleward
- Model agrees OK with CERES
- NIR & VIS zonal variability looks similar to total SW

NH-SH differences NIR/VIS ratio per latitude



- Positive values: NIR/VIS ratio is larger on NH than on SH; especially true under clear-sky between 20-70 deg. (note: locally, SH Africa and SA have largest NIR/VIS)
- CRE balance the hemispheric NIR/VIS ratio zonally & mirror the Clear-sky effects.
- But NIR/VIS ratio remains slightly larger on NH under all-sky conditions.


incoming
Units (Wm-2) solar TOA
340
(340, 341)
solar reflected
TOA
100
(96, 100)
thermal outgoing
TOA
239
(236, 242)
atmospheric
window
greenhouse
gases
79
(74, 91)
solar absorbed
atmosphere
latent heat
solar
down
surface
185
(179, 189)
24
(22,26)
solar
reflected
surface
161
(154, 166)
84
(70, 85)
20
(15, 25)
398
(394, 400)
342
(338, 348)
imbalance
0.6
(0.2, 1.0)
solar absorbed
surface
evapo-
ration
sensible
heat
thermal
up surface
thermal
down surface


Cloud Radiative Effects (CRE)
incoming
Units Wm-2 solar TOA
solar reflected
TOA
thermal outgoing
TOA
SW CRE
Net CRE
LW CRE
TOA
-47
-19
28
Atmosphere
7
7
0
solar absorbed
atmosphere
solar
down
surface
solar
reflected
surface
Surface
imbalance
-54
-26
28
solar absorbed
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ration
sensible
heat
thermal
up surface
thermal
down surface